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INITIAL MINERALOGICAL CHARACTERIZATION OF THE WINDY CRAGGY Cu-Co DEPOSIT, BRITISH COLUMBIA

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MICROMEDIA

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by

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ABSTRACT

A mineralogical study of drill core specimens from the Windy Craggy Cu-Co deposit, British Columbia has been completed. The study shows that the important sulphide minerals are pyrite, pyrrhotite, chalcopyrite, sphalerite, cobaltite and arsenopyrite. Pyrite contains up to about 3 per cent Co while coexisting pyrrhotite contains up to about 0.2 per cent. Discrete grains of cobaltite containing about 32 per cent Co occur in small carbonate veinlets in one of the samples. Fine-grained pyrite, less than 25 micrometres, is intergrown with coarse porphyrocrysts of pyrite. Cores of fine-grained aggregates of pyrite may be filled with chalcopyrite. Cobalt recoveries will be influenced by the variable cobalt content of sulphide minerals and the variable ratio of pyrite to pyrrhotite in the deposit. In addition, the highly variable ratio of fine to coarse pyrite may be the source of mineral processing problems. A detailed study of the mineralogical character of the ore, supported by extensive sampling, is recommended for the next phase of the project. Structures such as bedding and sedimentary deformation strongly suggest that the deposit is of sea-floor origin.

CARACTÉRISATION MINÉRALOGIQUE INITIALE DU GISEMENT DE CUIVRE ET DE COBALT DE WINDY CRAGGY (COLOMBIE-BRITANNIQUE)

par

P.R. Mainwaring

RÉSUMÉ

On a terminé une étude minéralogique de carottes de sondage provenant du gisement de cuivre et de cobalt de Windy Craggy (Colombie-Britannique). L'étude montre que les principaux sulfures sont la pyrite, la pyrrhotite, la chalcopyrite, la sphalerite, la cobaltite et l'arsenopyrite. La pyrite contient jusqu'à environ 3 % de Co alors que la pyrrhotite qui coexiste en contient jusqu'à environ 0,2 %. On a trouvé des grains séparés de cobaltite contenant environ 32 % de Co dans de petites veinules de carbonate dans l'un des échantillons. Des grains fins de pyrite, inférieurs à 25 micromètres, sont enchevêtrés avec de gros grains porphyriques de pyrite. Des noyaux d'aggrégats de pyrite à grains fins peuvent être remplis de chalcopyrite. La récupération du cobalt dépendra de la teneur variable en cobalt des minerais suflurés et du rapport variable entre la pyrite et la pyrrhotite dans le gisement. De plus, le rapport hautement variable entre la pyrite à grains fins et la pyrite à grains grossiers peut être une source de problèmes lors du traitement des minerais. On recommande d'effectuer une étude détaillée de la minéralogie du minerai avant de poursuivre le projet. Des structrures comme la stratification et la déformation sédimentaire suggèrent fortement que le gisement provient d'un fond océanique.

INTRODUCTION

Twenty specimens of BX drill core from the Windy Craggy Cu-Co deposit in extreme north-west British Columbia were submitted to CANMET by Mr. J. Gammon, Falconbridge Nickel Mines Ltd. Mr. Gammon reported that the deposit is large and represents a significant Canadian resource of cobalt. The company requested a mineralogical examination of the ore and subsequent advice on possible cobalt metallurgy. A mineralogical examination was undertaken at CANMET as part of Project 3.3.0.1.03, Mineralogical Studies of Marginal and Complex Ores. The purpose of this investigation is: 1) to characterize the samples in terms of sulphide mineralogy with special emphasis on the nature and distribution of cobalt-bearing minerals in order to establish which minerals must be recovered and, 2) to predict their liberation on grinding.

The samples were prepared both as polished and polished thin sections, the latter for examination of the associated gangue minerals. It is judged that the samples were collected for an initial reconnaissance study of the deposit because they display wide diversity in terms of textural types, proportion of sulphides and mineralogy. Consequently the samples may not be representative of the deposit as a whole.

MINERALOGY

All the samples contain variable proportions of cobaltian pyrite, pyrrhotite, and chalcopyrite, with minor to trace amounts of sphalerite, arsenopyrite, cobaltite, and marcasite. Sphalerite occurs as a major constituent in only 3 samples. Since pyrite is by far the most abundant sulphide mineral in the samples examined, the deposit appears to resemble the "pyritites" of New Brunswick. Based on the samples supplied, the deposit seems to consist of many layers of contrasting proportions of pyrite and pyrrhotite, with most of the chalcopyrite in the pyrite-rich layers.

COBALTIAN PYRITE

In most sections of core examined, pyrite occurs as both anhedral and euhedral grains (Figures 1,2). Anhedral grains may form colloform structures, aggregates of these structures, or tightly packed anhedral grains. Euhedral pyrite occurs in the same sections and intermixed with the anhedral variety. The latter is commonly devoid of inclusions of other minerals. Both forms of pyrite seem to have crystallized in situ and may be considered therefore, as primary. The grain size of pyrite is highly variable; the range is from less than 25 micrometres to several millimetres. This range can occur in a single core specimen and probably reflects deposit-wide variation. The average grain size of pyrite in all samples is about 50 micrometres. Euhedral grains of pyrite rarely contain coarse inclusions of gangue minerals and, although pyrrhotite inclusions are very rare, chalcopyrite inclusions are more common. Pyrite which occurs as framboids or sections of botryoidal masses often contains inclusions of gangue minerals and sulphides defining the growth surfaces (Figure 3). The relatively large, euhedral grains of pyrite which are commonly several hundred micrometres in size (Figure 4) resemble the porphyroblasts in more intensely metamorphosed deposits. No textural evidence, such as gangue inclusions or rotational growth, exists to suggest that these grains are metamorphically derived.

PYRRHOTITE

Pyrrhotite, like pyrite, occurs in a wide variety of grain sizes although none is as coarse as some of the pyrite. Common grain-size

variation ranges between about 50 micrometres and 0.5 millimetres. This variation can occur in one drill core specimen and varies also between specimens. As indicated previously, inclusions of pyrrhotite are extremely rare in pyrite; pyrrhotite commonly surrounds the pyrite grains but never the reverse.

CHALCOPYRITE

Chalcopyrite occurs as anhedral masses intergrown with pyrrhotite and, rarely, as inclusions less than about 10 micrometres in pyrite. Pyrite containing fine chalcopyrite inclusions does not occur in all specimens; the inclusions are more common in the specimens that contain abundant framboidal pyrite and lesser amounts of massive pyrite.

SPHALERITE

Sphalerite occurs commonly in pyrrhotite, chalcopyrite and in gangue minerals, especially primary carbonates. The sphalerite is pale red in thin section, indicative of a moderate iron content. In the samples examined, all the sphalerite occurs as small (less than 75 micrometres), discrete grains which are disseminated in the host minerals. There are no inclusions of other minerals in the sphalerite.

COBALTITE

Discrete grains of cobaltite were found in only one sample. These grains occur in a narrow carbonate veinlet which is less than 0.5 mm wide (Figure 5). The individual grains of cobaltite are less than about 40 micrometres in maximum size.

MARCASITE

This mineral occurs in only two samples, in volumetrically minor amounts. All the grains are characterized by radial structure, which may be original. There are no intergrowths of pyrite and marcasite to suggest conversion of marcasite to pyrite. The marcasite occurs in gangue minerals and is never included in other sulphide minerals. This fact might suggest that marcasite may be formed later than the other sulphide minerals. Typical grain sizes range from about 100 micrometres to several hundred micrometres.

ARSENOPYRITE

One specimen of drill core (WC 3516) contains many subhedral to euhedral grains of cobalt-bearing arsenopyrite. All grains of arsenopyrite occur in pyrrhotite. Average grain size ranges between about 10 and 30 micrometres.

GANGUE MINERALS

Detailed mineralogy of the gangue minerals has not been undertaken in this initial phase of the study. Preliminary examination of polished thin sections indicates that they are carbonates and silicates. The carbonates, including dolomite, ankerite, and siderite are more commonly associated with the pyrite-rich zones than with the pyrrhotite-rich ones. Often chert is associated with the latter. Silicate minerals identified include chlorite, stilpnomelane, possible iron amphibole and clay minerals.

MINERALOGICAL TEXTURES

Liberation characteristics of the Windy Craggy ores are directly related to the various mineralogical textures and grain sizes. The textures may be divided into small-scale and large-scale features. Small-scale features include grain-to-grain relationships and mutual inclusions of one mineral in another. Many of these have been discussed in the preceeding section.

PYRITE

Cobalt-bearing pyrite is the most abundant mineral in the deposit and as such, its relationships with other minerals are extremely important in mineral beneficiation studies. In the specimens examined, fine-grained pyrite contains inclusions of either extremely small, rare grains of pyrrhotite or larger and more abundant inclusions of chalcopyrite. The latter are small with respect to the host pyrite grain, generally less than about 20 micrometres. Gangue inclusions in coarse pyrite are volumetrically minor and appear to be silicate minerals rather than carbonates. The paucity of gangue inclusions in this pyrite is illustrated in Figure 6. In some sections a high proportion of the finer grain size fraction of chalcopyrite occurs in the finest fraction of anhedral pyrite. This proportion approaches about 50 per cent in some samples.

Large-scale features in the samples relate to inhomogeneity throughout the particular sample. Figure 7 shows regions of chalcopyrite + pyrite enrichment which probably reflect original sedimentary layering.

CHALCOPYRITE

The presence or absence of inclusions in chalcopyrite does not seem to be systematically related to a single factor. In a single specimen both inclusion-rich and inclusion-poor chalcopyrite exist. Chalcopyrite commonly fills cracks in the more brittle pyrite grains (Figures 6,8) and very commonly in pyrite where it may form layers or radial structures, probably again related to fracture and flowage (Figure 9). Cores of some of the aggregates of fine euhedral pyrite are filled by chalcopyrite (Figure 1).

PYRRHOTITE

The most common occurrence of pyrrhotite is in massive aggregates with pyrite and less commonly with massive chalcopyrite. Massive pyrrhotite often exhibits a pronounced grain orientation (Figure 10), probably the result of local stress. Minor amounts of pyrrhotite occur in pyrite framboids and as isolated grains in gangue. Some pyrrhotite occurs as almost monomineralic aggregates with negligible amounts of intergrown chalcopyrite. These are probably pyrrhotite-rich layers in the deposit.

MINERAL CHEMISTRY

Electron microprobe analyses of pyrrhotite, pyrite, cobaltite and sphalerite have been done on a number of specimens. Analyses were not performed on the smaller grains of the minerals because of unreliability in the positioning of the electron microprobe. A summary of compositional data is presented in Table 1.

Based on the limited number of samples examined, cobalt distribution seems to be related to the abundance of botryoidal and fine grained pyrite. This pyrite is unzoned with respect to cobalt and coexists with a cobalt-rich pyrrhotite. Cobaltite grains occur in a very small veinlet which suggests that cobaltite is stable in this environment. Increased levels of cobalt might be expected to occur in sections which contain remobilized sulphide minerals. Samples taken from ten foot assay

composites for silver did not contain any observable discrete silver minerals.

COBALT

Analyses of pyrite and pyrrhotite for cobalt indicate that both minerals contain highly variable amounts in the sections studied. Pyrite typically contains between 0.03 wt % (limit of detection) and a maximum of about 1.5 wt % in the same section. Much, but not all, pyrite enclosed in pyrrhotite contains more cobalt than associated pyrite enclosed in gangue or chalcopyrite. Too few samples have been analysed to determine reliably if a high correlation exists between a specific textural type of pyrite and cobalt content. Large grains of euhedral pyrite which occur in the same specimen as framboidal pyrite do not generally contain as much cobalt as the framboidal pyrite (Table 1). The maximum cobalt content of pyrite in all the samples is about 3.2 wt %. Microprobe analyses of both pyrite and pyrrhotite indicate that neither mineral is zoned with respect to cobalt content.

Cobalt content of the pyrrhotite typically ranges between limit of detection (0.03 wt % Co) and a maximum of about 0.2 wt %. The discrete grains of cobaltite that occur in one specimen (WC3517) contain an average of 32.4 wt % Co and 42.0 wt % As.

SPHALERITE

The sphalerite averages about 7 wt. per cent iron and 58 wt. per cent zinc (Table 1). Variation in iron content is generally about 1 wt. per cent within a specimen. Composition of sphalerite is shown in Table 1. Sphalerite which is associated with gangue minerals, especially carbonates as in sample WC 41847, has less iron than that associated with Fe-bearing sulphide minerals as in sample WC 3515.

IMPLICATIONS FOR MINERAL PROCESSING

Based on the samples examined, observations which affect metals recovery are the following:

- pyrite is the most abundant cobalt-containing mineral, although local concentrations of cobaltite occur;
- fine-grained botryoidal pyrite has more cobalt than coarser grained porphyrocrystic pyrite;
- fine grained botryoidal pyrite has abundant inclusions of chalcopyrite;
- average grain size of botryoidal pyrite is about 60 micrometres;
- there are substantial local variations in grain size in the samples, and, probably, throughout the orebody.

Copper and cobalt recovery are expected to depend on grain-size of pyrite and chalcopyrite, together with the relative proportions of these minerals. In addition, the high degree of variability in the ratio of pyrite to chalcopyrite and pyrrhotite, due largely to original mineralogical layering, will also play a role. In specimens that contain no strong compositional layering, the ratio of fine grained aggregates of pyrite to euhedral porphyrocrysts varies from 10:1 to 20:1.

Modal analysis, determined by image analysis of specimens that were relatively uniform in sulphide mineral ratios, gave the following results:

SAMPLE NO.	PYRITE	PYRRHOTITE	CHALCOPYRITE	GANGUE
41838	11	63	4	23
41842	33	29	13	26
41849	52	28	4	16

As indicated by these few determinations, there is a wide range in the ratio of pyrite:chalcopyrite although further work should extend this series of measurements. The remaining specimens exhibited wide variations on the specimen scale and image analysis was not attempted.

STRUCTURE

The layered nature of the sulphide minerals within many samples (Figure 11,12) together with abundant colloform pyrite strongly suggests that the sulphide minerals are products of sea-floor fumarolic activity. This is

substantiated by the manganese-rich carbonate minerals associated with the sulphides and by sedimentary-like structures such as compaction features, brecciation and carbonate textures. Layering throughout the deposit appears to be defined by varying proportions of pyrite and pyrrhotite although, with the few samples studied, little can be said regarding the mineralogical zonation. Effects of metamorphism on the sulphides, as gauged by penetrative fabric, deformation, and remobilization, appear to be local. Manganese is usually enriched in the more distant sulphides around sea-floor vents, as is cobalt and silver. It is possible that the samples examined have come from a 'distal' sulphide fumarloic deposit. Implications of this are discussed below.

REQUIREMENTS FOR FURTHER WORK

The samples supplied are from widely spaced locations and were not collected with knowledge of their microscopic mineral content. Now that specified types of cobalt-bearing pyrite have been identified and such wide variation in cobalt content has been established, a more detailed sampling program should be undertaken in an attempt to determine the following:

- the distribution of grain size variation of cobaltian pyrite;
- the correlation of cobalt in pyrite and pyrrhotite;
- association of cobaltite-bearing veins;
- variation of cobalt content of pyrite in different associations;
- identification of silver-bearing minerals;
- representative size analyses of minerals and their liberation characteristics.

Similarities exist between the Windy Craggy deposit and the complex sulphides of the New Brunswick type, such as Caribou. These similarities include the relative enrichment of cobalt-bearing pyrite over pyrrhotite, the fine-grained, complexly intergrown nature of the sulphides and the low grade of metamorphism. Based on the few samples supplied for this study, the mineralogy at Windy Craggy is simpler. A comparative study between the Caribou-type fine-grained sulphides and those at Windy Craggy should be undertaken in order to anticipate metal processing problems and to optimize cobalt and copper recoveries. A detailed drill core sampling program would

be the first step in this study.

It is important to note that the absence of complex structural relations at Windy Craggy and the apparently simple sulphide mineralogy could be interpreted to mean that the potential exists for an extremely large tonnage deposit with substantial lateral continuity and uniform grade.

CONCLUSIONS

The following salient points have been established in this preliminary examination of the Windy Craggy samples:

- the most abundant cobalt-bearing mineral is pyrite;
- cobalt content is highly variable, ranging from the detection limit to about 3%;
- associated pyrrhotite also has significant cobalt content;
- assay values for cobalt can be attributed to solid solution in pyrite and pyrrhotite;
- other cobalt-bearing minerals which occur in small quantities are arsenopyrite and cobaltite;
- fine-grained pyrite generally has greater cobalt and chalcopyrite content than does coarse euhedral pyrite;
- based on assay data, silver appears to be associated with sphalerite occurrence; however, silver was not detected in any mineral examined.

The occurrence of discrete cobaltite bearing veinlets should be examined closely because they may be related to local deformation in the deposit and may be the source of significant cobalt enrichment. Detailed investigation of metal ratios by contour mapping will show if systematic variations occur and if these variations could point toward areas of cobalt or precious-metal enrichment.

If further work substantiates the concept that the Windy Craggy deposit is of a distal sea-floor fumarolic type, then the deposit may be a landward equivalent of the present day sulphide accumulations on the Canadian portion of the Juan de Fuca spreading ridge, off the British Columbia coast.

Table 1 - Electron microprobe analyses of pyrite and pyrrhotite

SAMPLE NO.		AVG. WT. % Co	RANGE	ASSAY WT. % Co	FOOTAGE	DRILL HOLE #
41840.00	Pyrite	0.92	0.2 - 3.2	0.18	965.00	9.82
	Pyrrhotite	0.19	0.12 - 0.24			
41818.00	Pyrite	0.12	0.0 - 0.18	0.06	1084.00	9.82
	Pyrrhotite	0.05	0.0 - 0.08			
41839.00	Pyrite	1.2	0.3 - 2.4	0.22	1146.00	9.82
41838.00	Pyrite	1.6	0.11 - 2.3	0.18	1154.00	9.82
41841.00	Pyrite	0.98	0.10 - 1.2	0.13	1342.00	9.82
3517.00	Pyrite	1.21	0.0 - 3.2	0.11	1020.00	9.82
	Pyrrhotite	0.13	0.12 - 0.24			

Electron microprobe analyses of sphalerite

SAMPLE NO.	Fe WT. %	Zn WT. %	S WT. %	TOTAL	MOLE % FeS
41847.00	6.4	60.9	32.5	99.8	6.2
3515.00	8.3	56.9	33.0	98.2	7.3

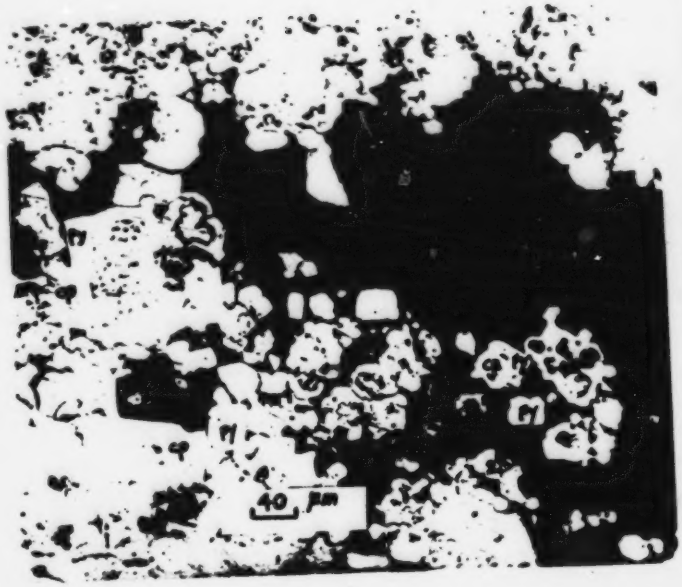

Figure 1: Simple intergrowths of euhedral and anhedral pyrite (py) with chalcopyrite (cp). (41844)

Figure 2: Spherical and cubic pyrite (py) grains intergrown with pyrrhotite (po). (3516)

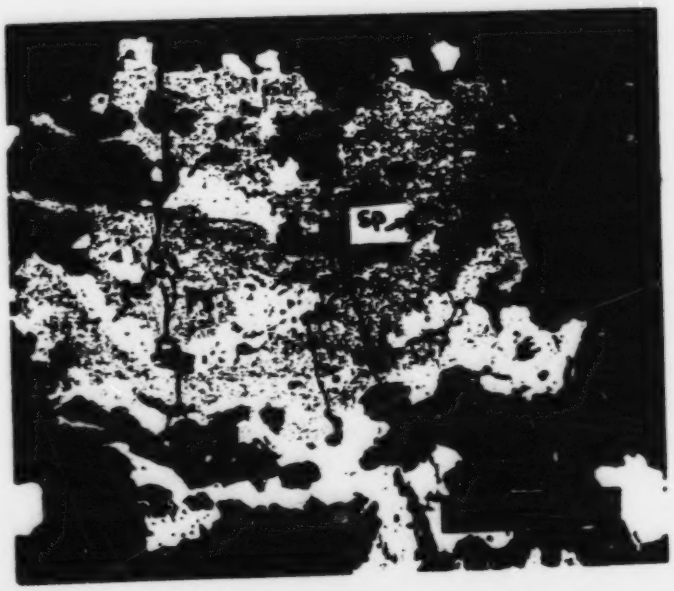

Figure 3: Pyrite (py) with concentric or radial structure with intergrown pyrrhotite (po) and sphalerite (sp). (41839)

Figure 4: Pyrite porphyrocryst (py) in finer pyrite intergrown with pyrrhotite (po). (3518)

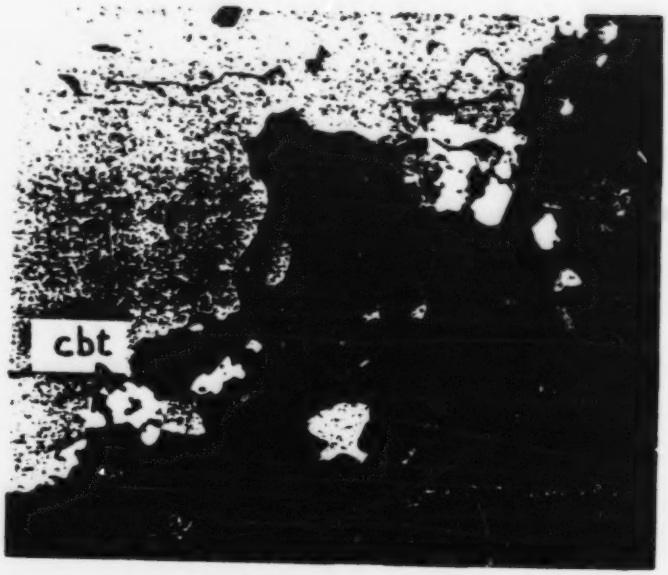

Figure 5: Fine cobaltite (cbt) in calcite vein and intergrown with chalcopyrite (cp). (3517)

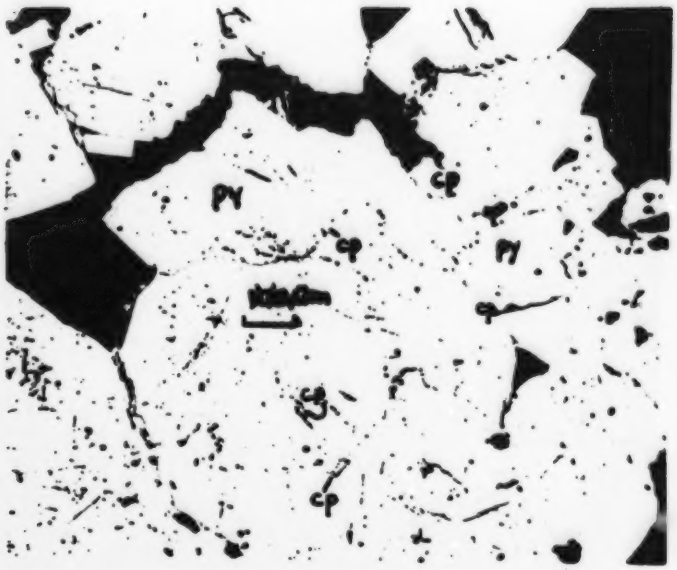

Figure 6: Fine chalcopyrite (cp) intergrown with coarse pyrite (py). (41845)

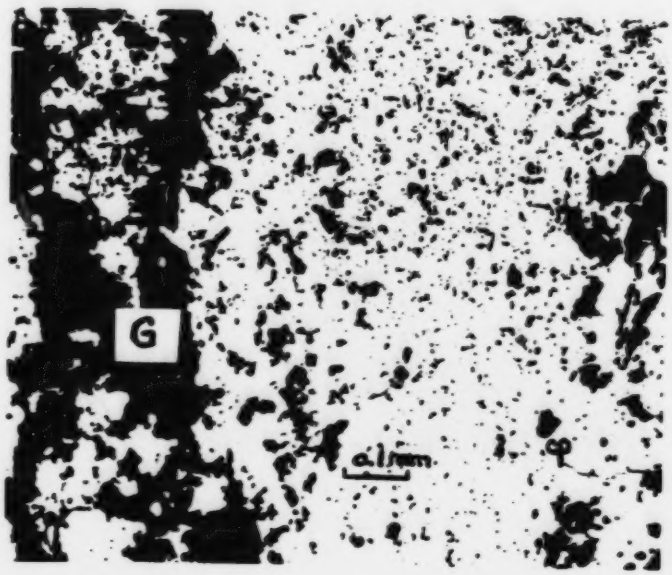

Figure 7: Sedimentary-like layering involving chalcopyrite (cp), pyrite (py) and gangue (G). (41847)

Figure 8: Fractures in pyrite (py) filled by chalcopyrite (cp). (41849)

Figure 9: Pyrite (py) with radial and concentric intergrowth of chalcopyrite (cp). (41839)

Figure 10: Pronounced grain orientation in massive pyrrhotite (po). Crossed nicols. (3518)

Figure 11: Local deformation in massive sulphides. Possibly slumping and brecciation. (41838)

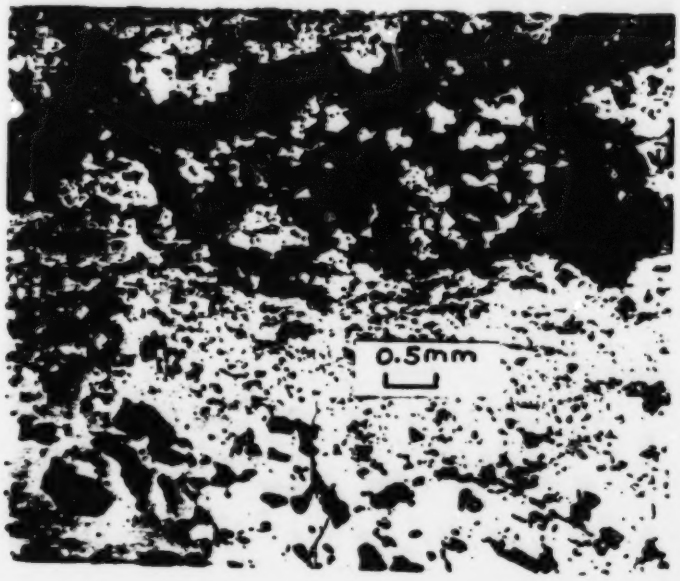

Figure 12: Fine-scale primary layering involving variable proportions of pyrite (py) and pyrrhotite (po). (41847)